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Title: Reactor Neutrino Spectral Distortions Play Little Role in Mass Hierarchy Experiments

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Reactor Neutrino Spectral Distortions Play Little Role in Mass Hierarchy Experiments

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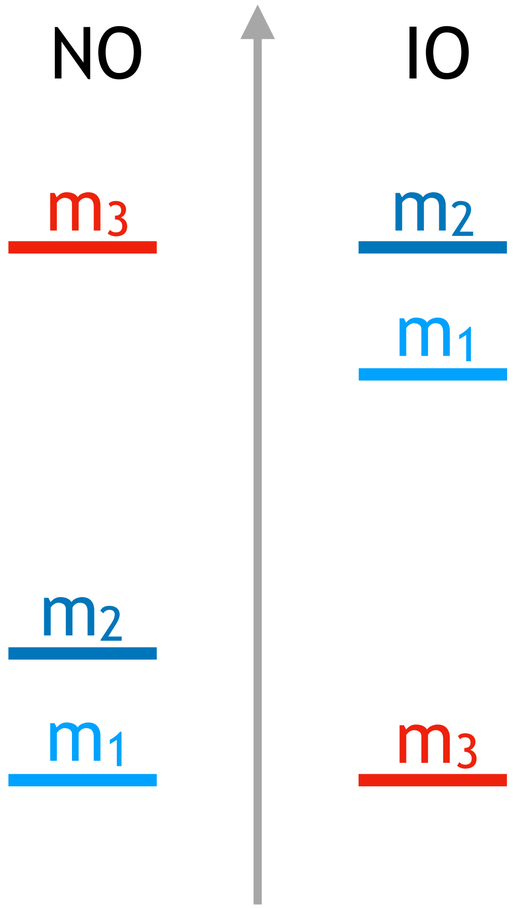
APS April Meeting
April 16, 2019

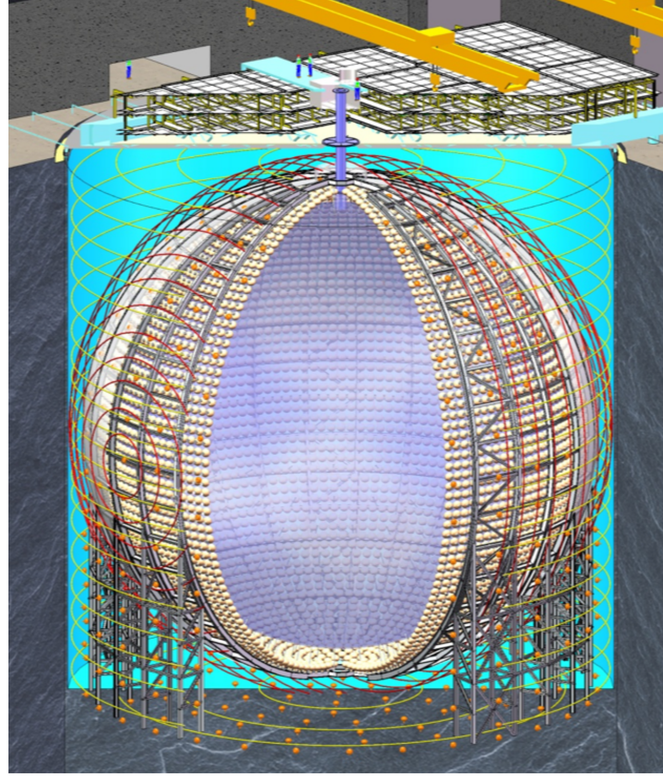
The Neutrino Mass Hierarchy Problem

ν_1, ν_2, ν_3



JUNO

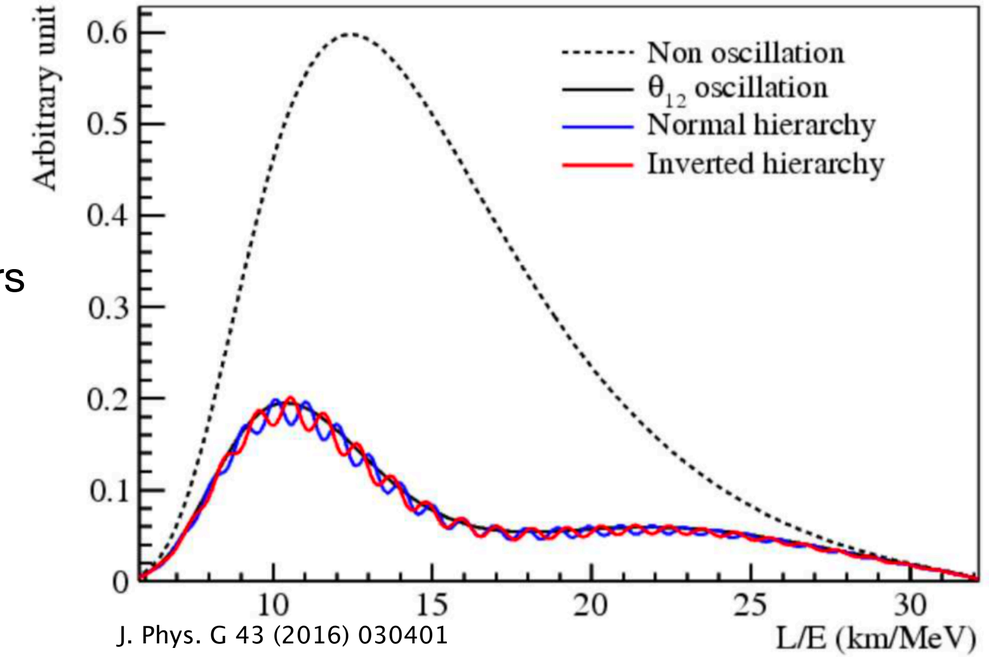
$$
\begin{aligned}
P_{ee} = 1 &- \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21}) \\
&- \sin^2(2\theta_{13})\sin^2(\Delta_{31}) \\
&- \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{21})\cos(2|\Delta_{31}|) \\
&\pm \frac{\sin^2(\theta_{12})}{2}\sin^2(2\theta_{13})\sin(2\Delta_{21})\sin(2|\Delta_{31}|).
\end{aligned}
$$



- Reactor antineutrino oscillation experiment
- 20 kT liquid-scintillator-doped mineral oil
- 53 km baseline
- Goal: resolve the neutrino mass hierarchy to better than 3σ within six years

- 2017: “The benefits of a near detector for JUNO” arXiv:1710.07378 [hep-ph]

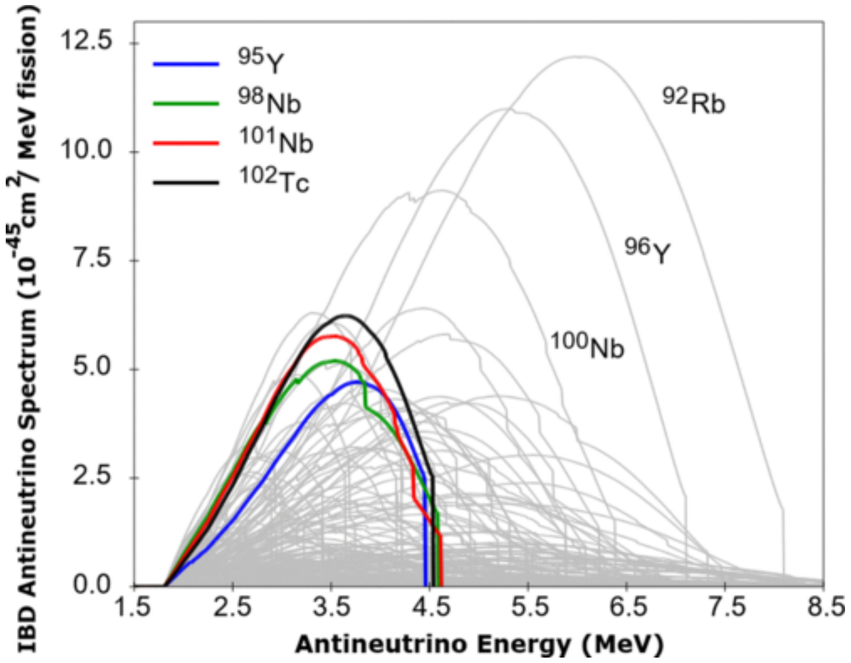
  “the **micro-structure present in antineutrino fluxes** from nuclear reactors makes it essential to experimentally determine a reference spectrum with an energy resolution very similar to the one of JUNO.”



J. Phys. G 43 (2016) 030401

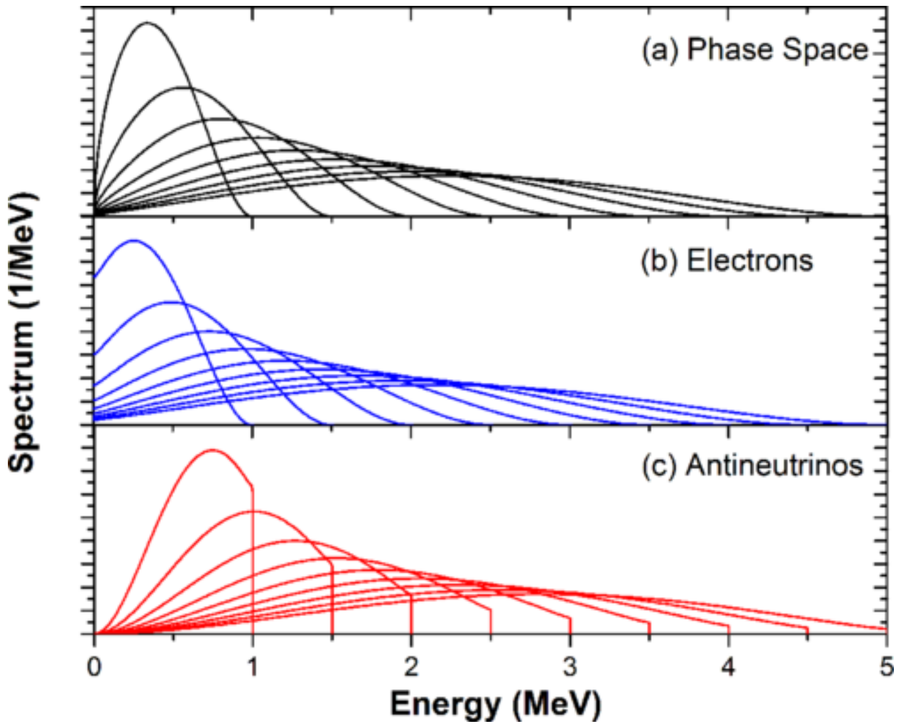
micro-structure present in antineutrino fluxes

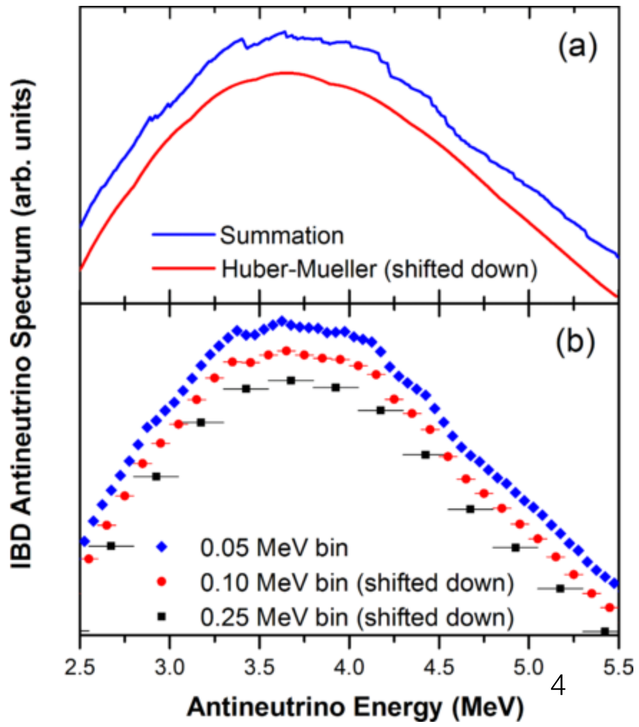
"Revealing fine structure in the antineutrino spectra from a nuclear reactor."
Phys. Rev. C **98**, 014323. A. Sonzogni, M. Nino, and E. A. McCutchan



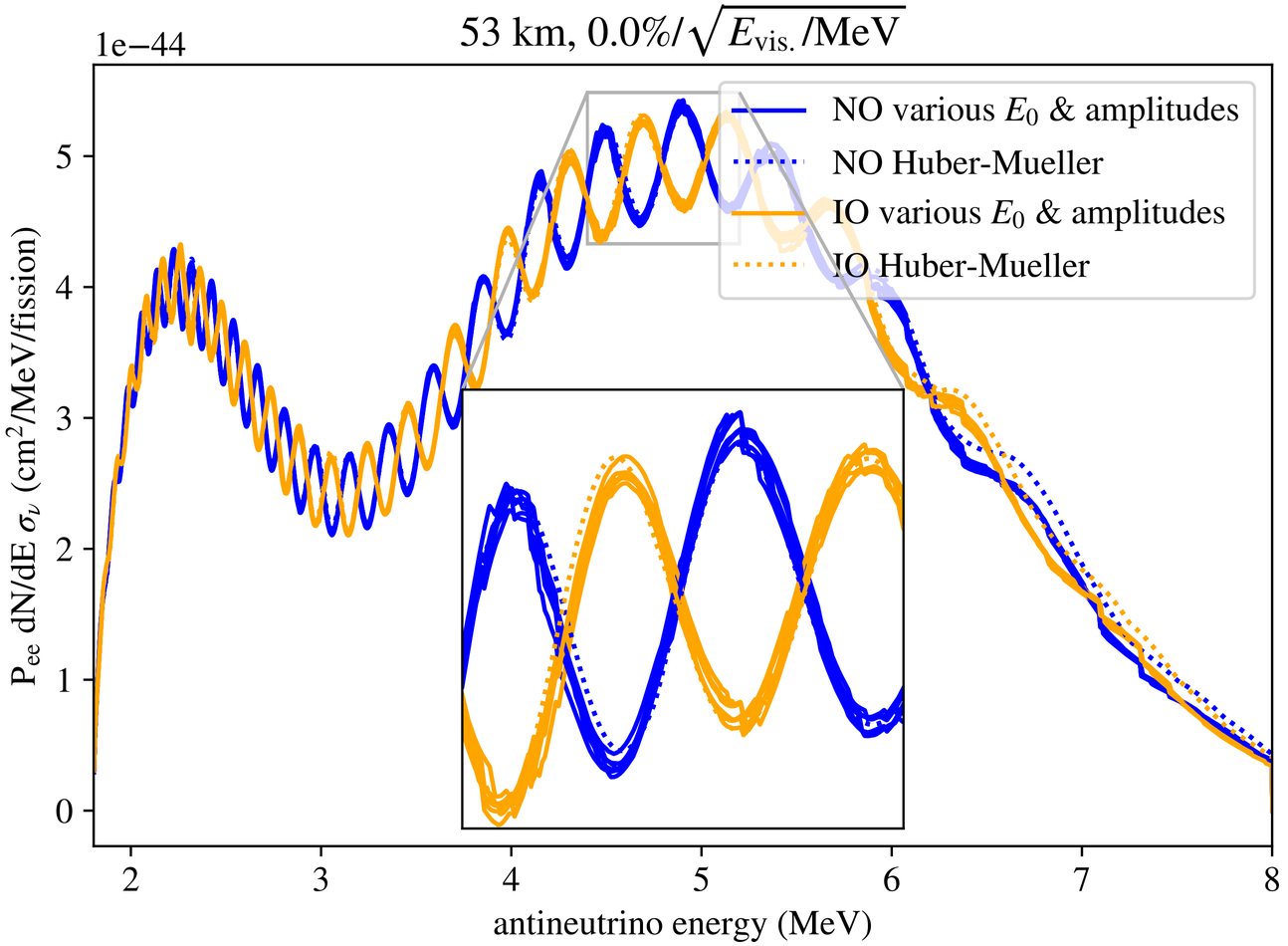
- **Reactor antineutrino spectrum is the sum of many individual beta decay spectra**

Coulomb enhancement of low energy betas
→ cutoffs in antineutrino spectra





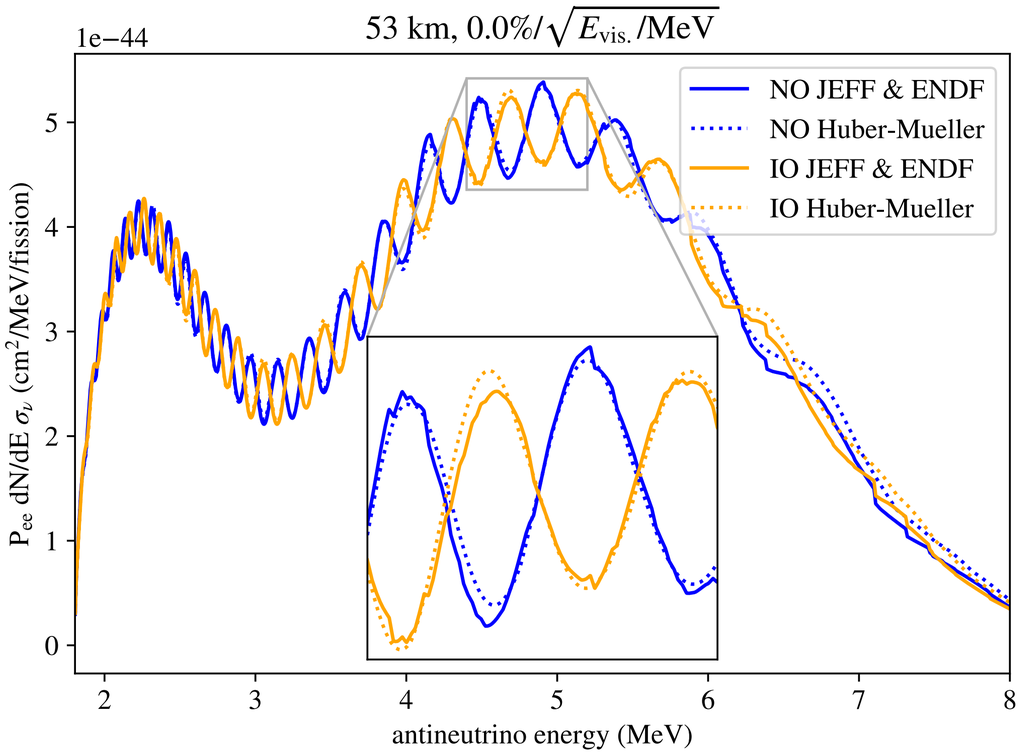
And, the fine structure is uncertain…

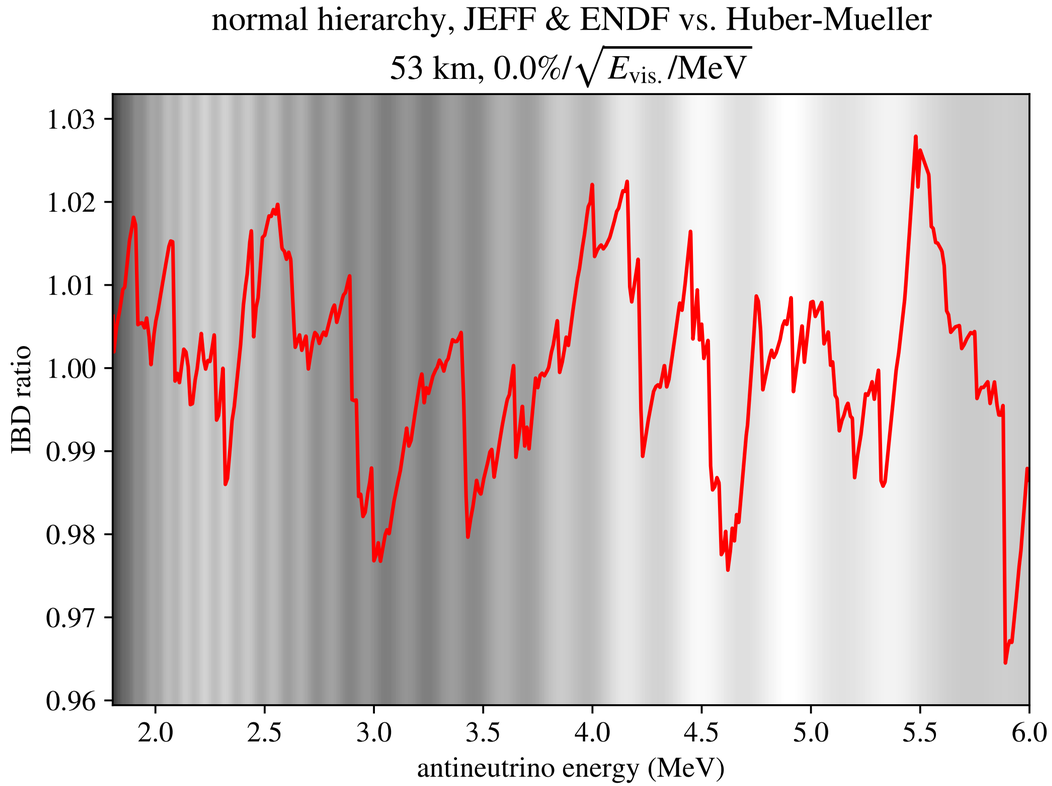


We generate extremely conservative fine-structure error margins by simulating many different reactor antineutrino spectra with endpoint energies and amplitudes sampled from throughout and beyond their experimental uncertainties.

What impact will this fine structure have on mass hierarchy experiments?

- We reproduce summed nuclear reactor spectra
- We model oscillation physics, inverse beta decay cross section
- Is seeming alignment between sawtooths and oscillations a problem?



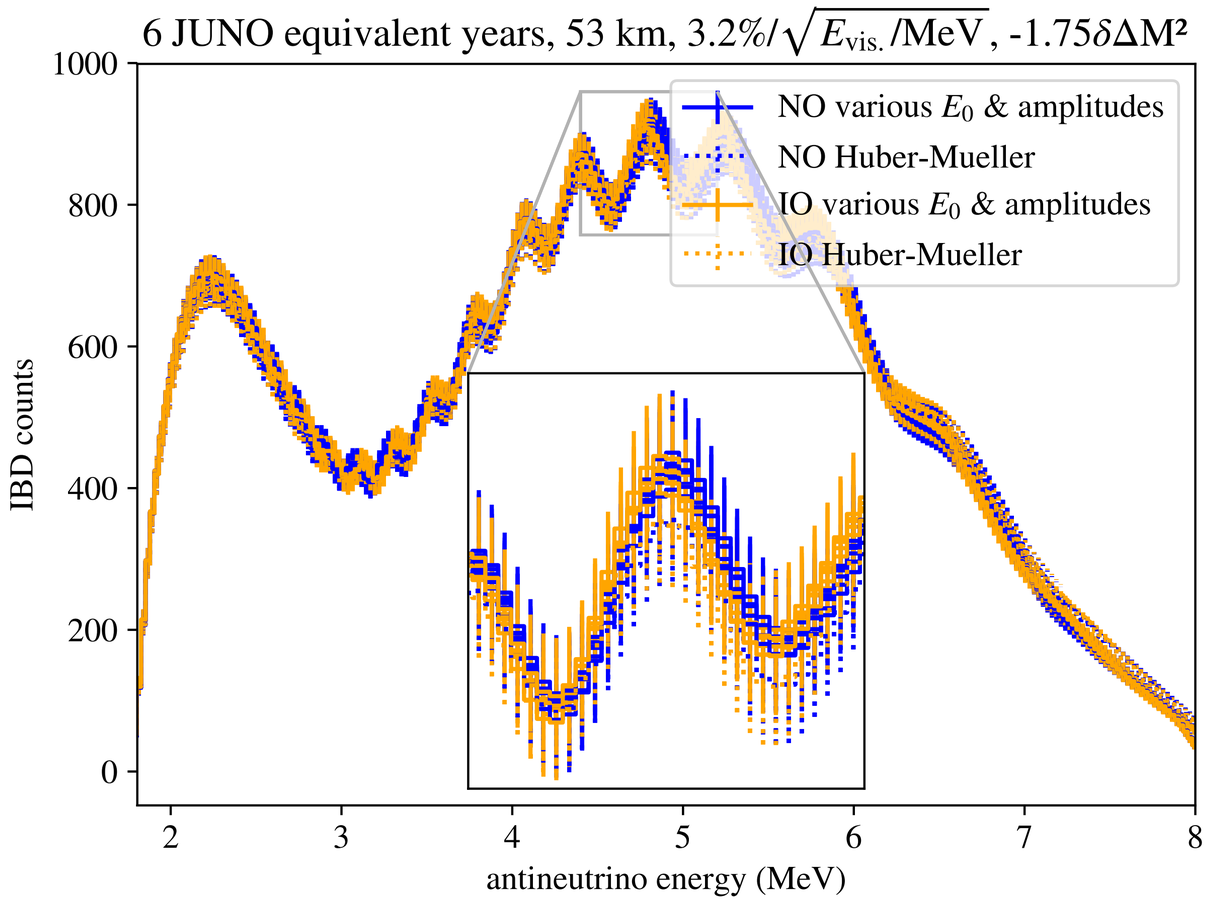


we consider the ‘worst-case’ scenario

- Degenerate parameters:
  What if nature chooses oscillation parameters easily fitted by the wrong hierarchy?
  Phys. Rev. D 87, 033005 (2013)

- JUNO aims to achieve 3% energy resolution.
  We assume only 3.2% is achieved.

- Given fine structure and statistical uncertainties, the hierarchy is unresolvable in energy space after 6 JUNO-equivalent years, *but*…

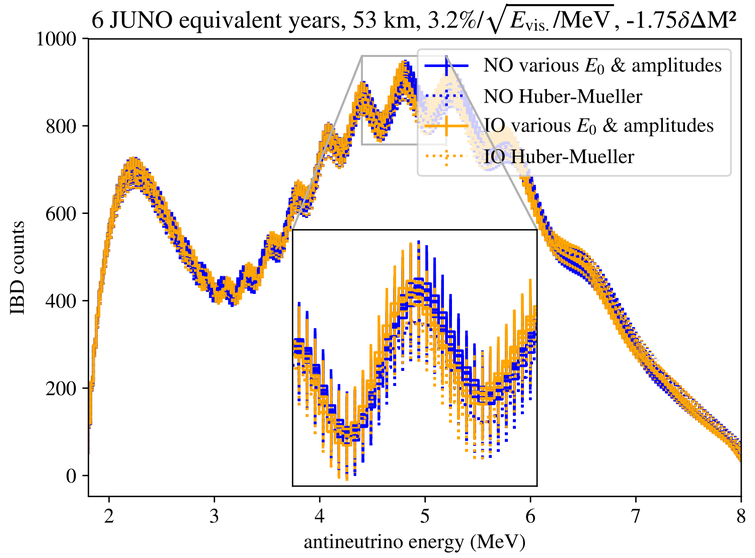


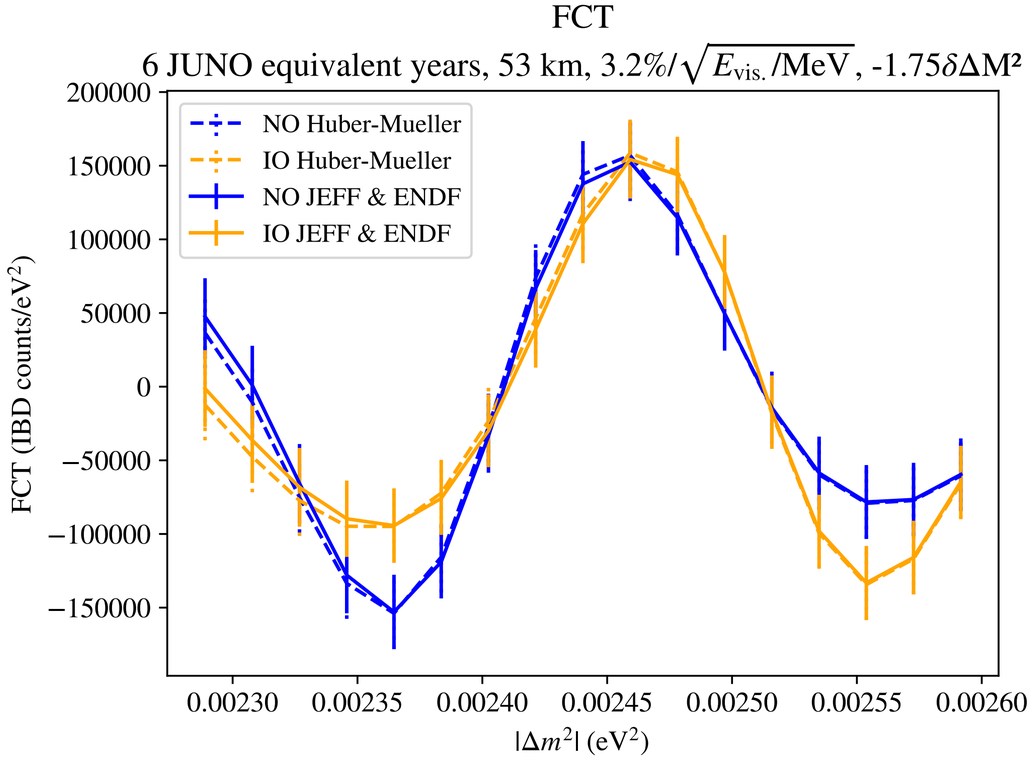
Fourier analysis

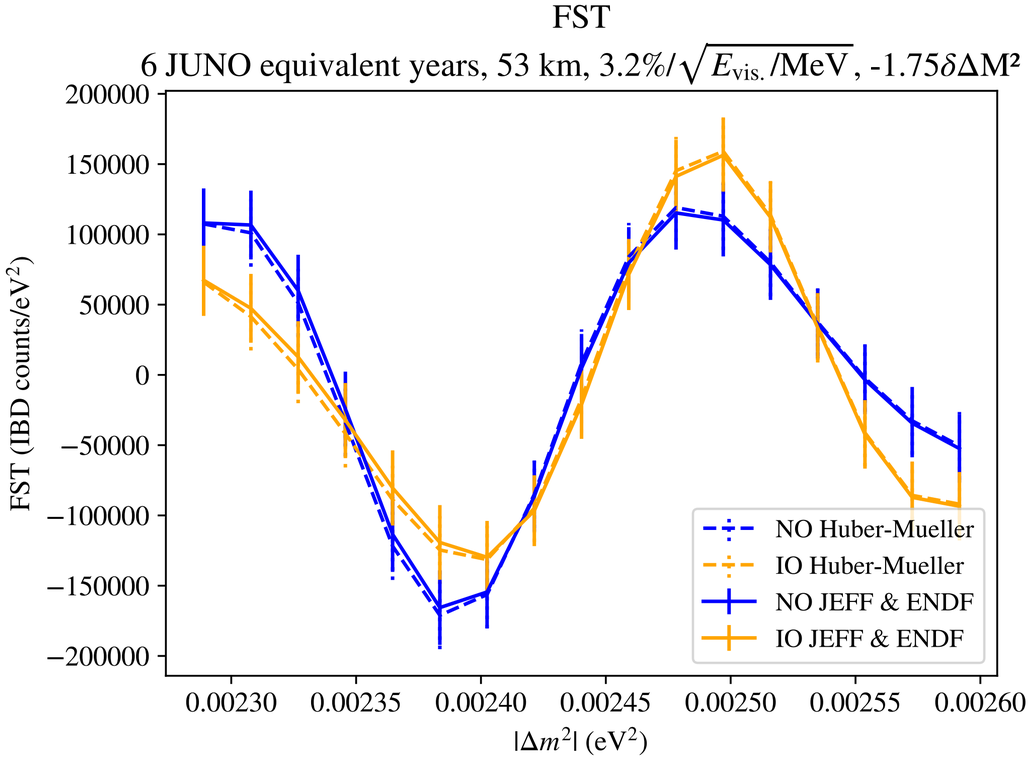
Restricting analysis to the experimentally allowed region in $|\Delta m^2|$ frequency space separates the hierarchies

$$F(\omega) \equiv 2\Delta \frac{L}{E} \sum_i g\left(\omega \left[\frac{L}{E}\right]_i\right) f\left(\left[\frac{L}{E}\right]_i\right)$$

$$\sigma(\omega) = 2\Delta \frac{L}{E} \sqrt{\sum_i g^2\left(\omega \left[\frac{L}{E}\right]_i\right) \sigma\left(\left[\frac{L}{E}\right]_i\right)^2}$$

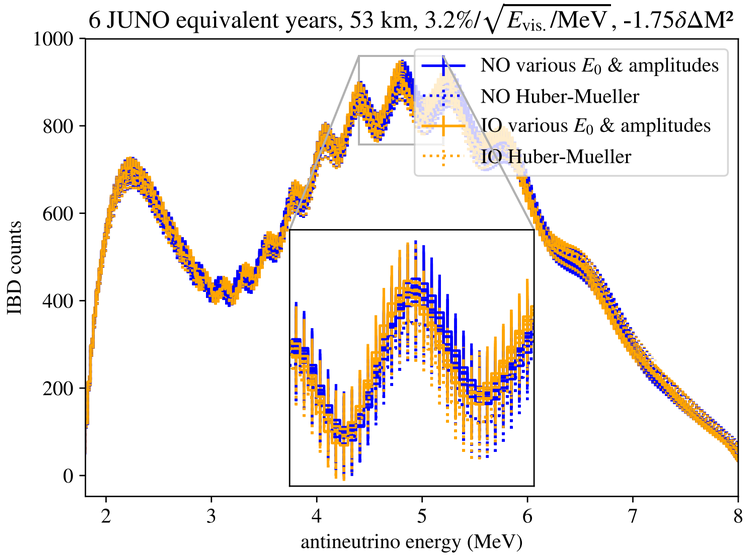


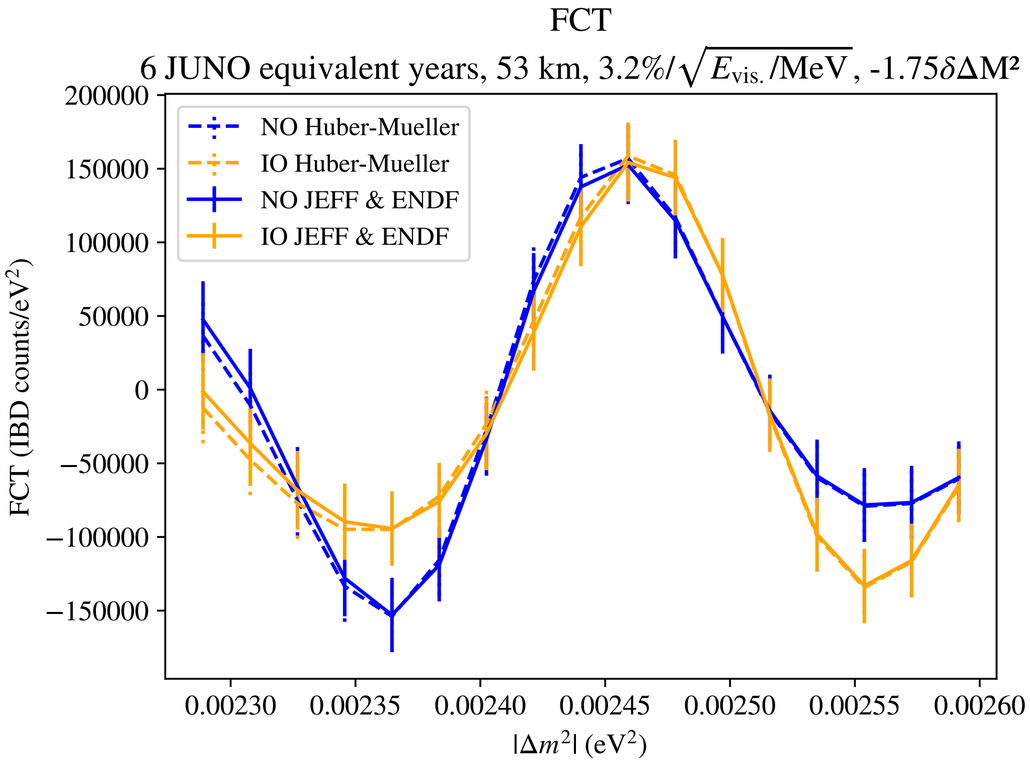


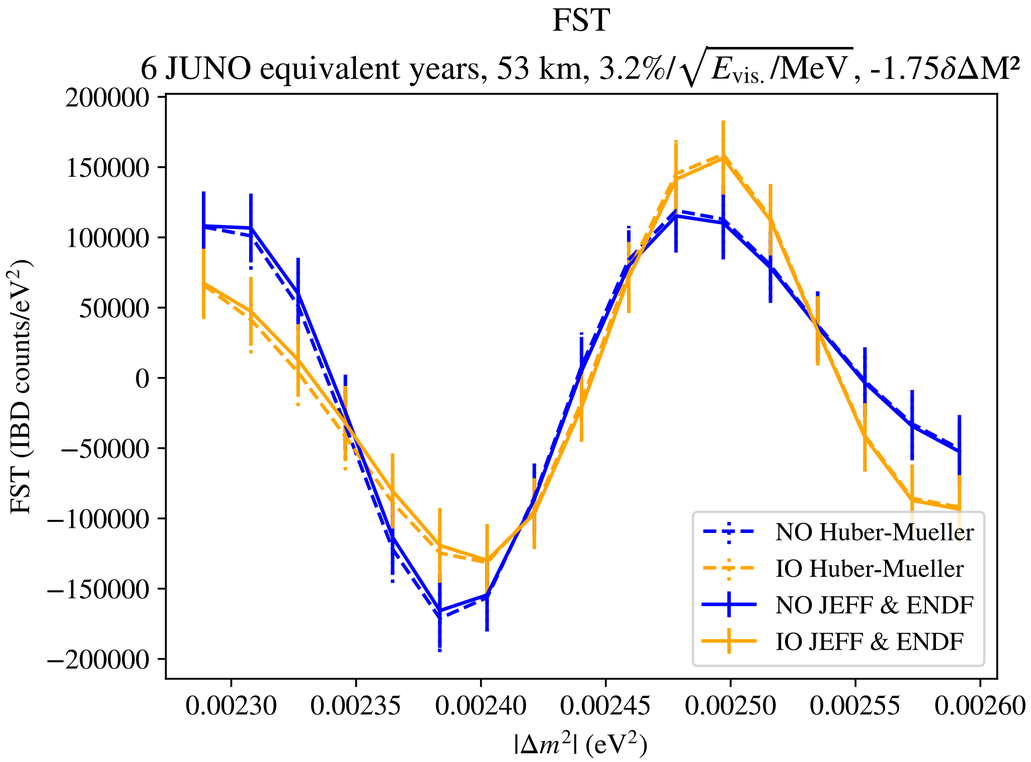


Why does this work?

1. Fourier analysis is sensitive to phase differences, which are small in any given energy bin



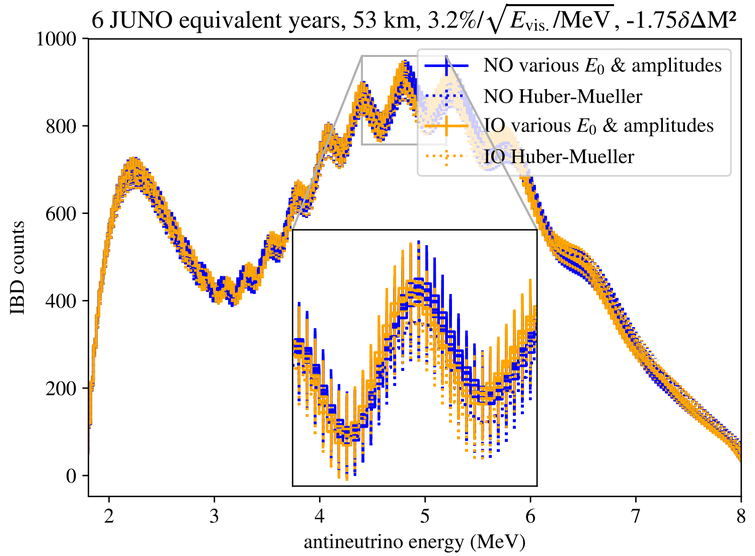


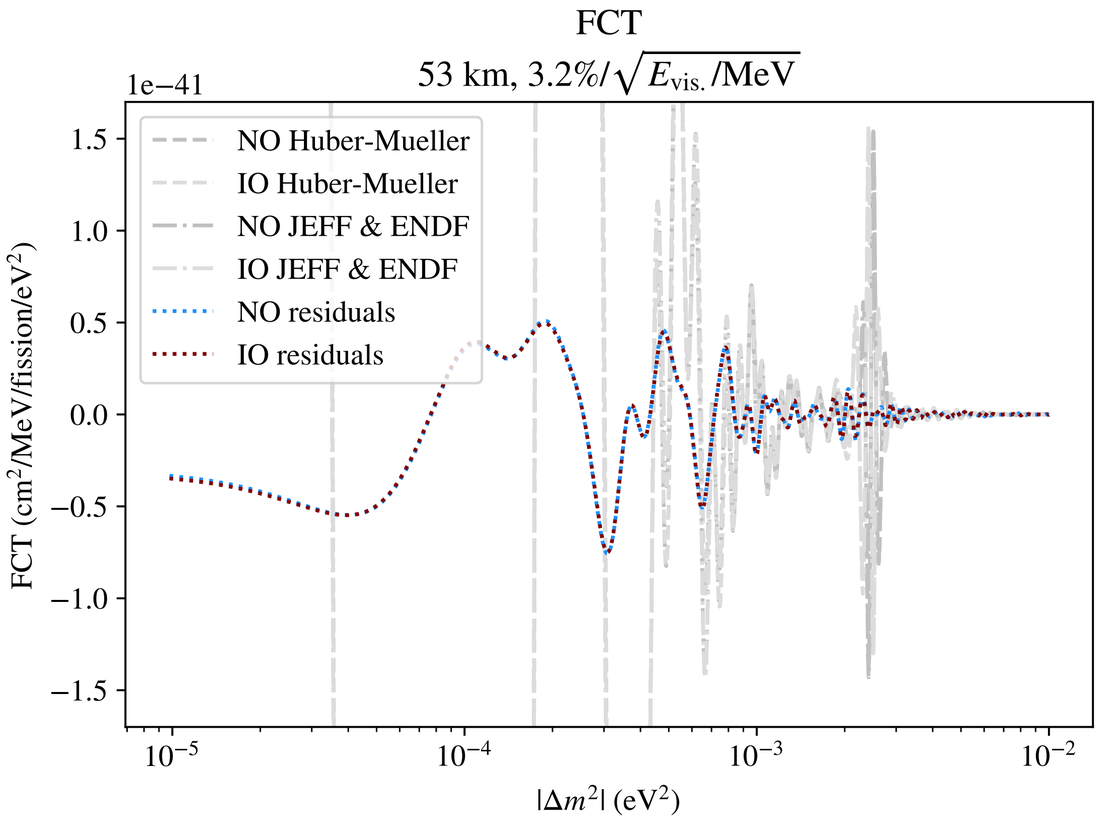


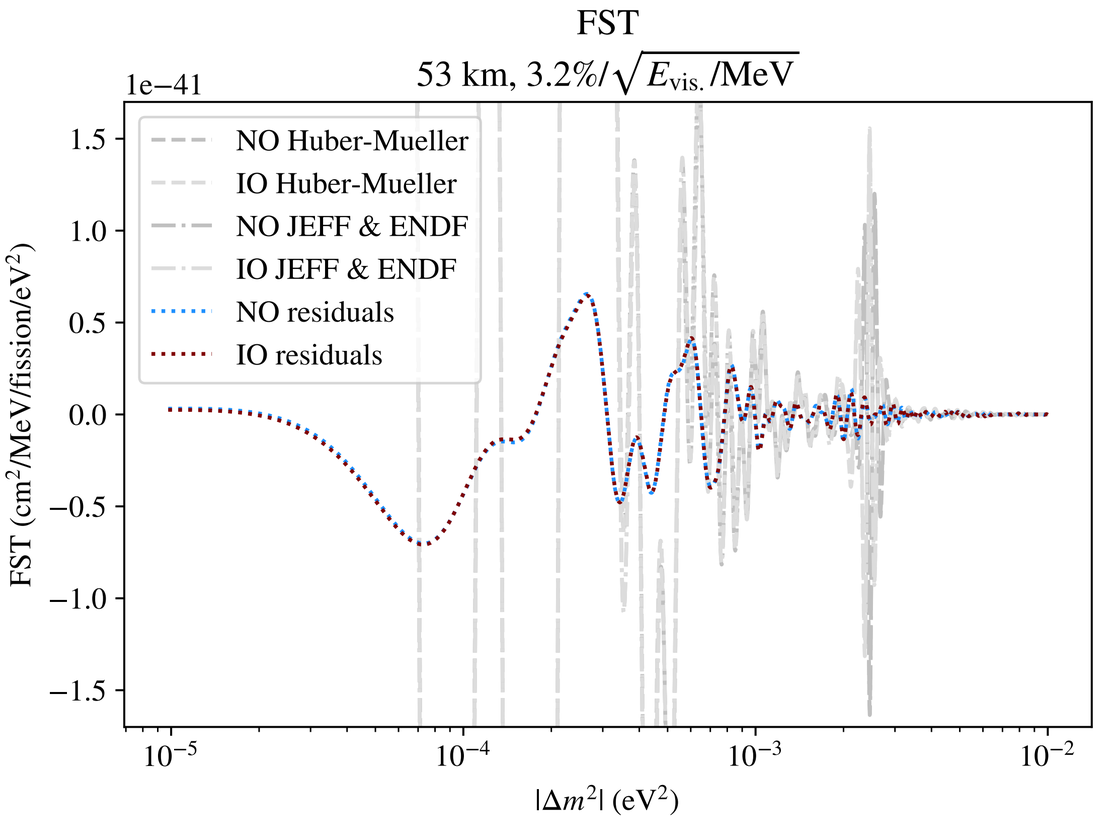
Why does this work?

1. Fourier analysis is sensitive to phase differences, which are small in any given energy bin

2. Restricting to experimentally allowed $|\Delta m^2|$ window filters out the most fine structure effects, because it is not coherent with hierarchy-dependent oscillations



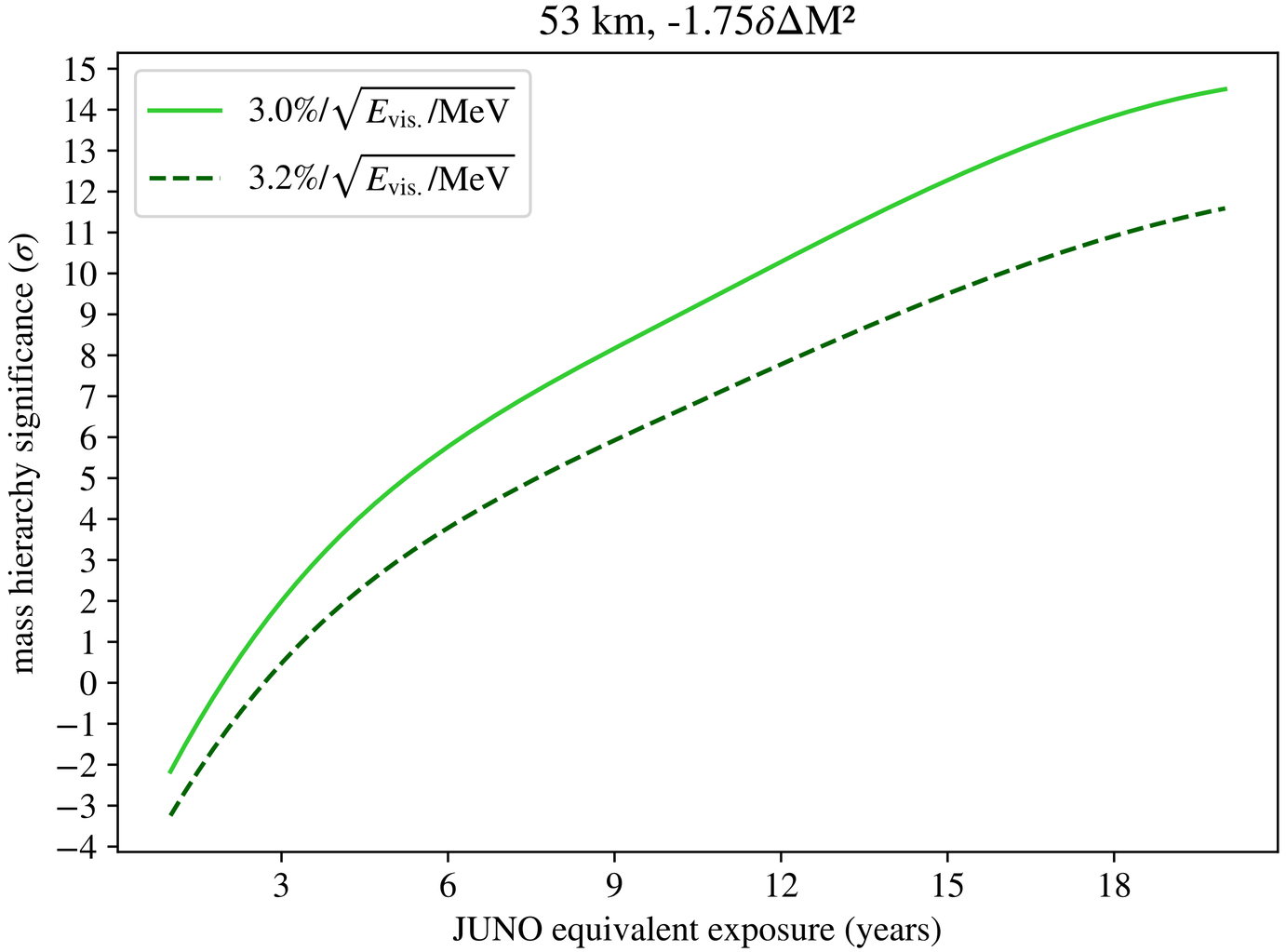




The Impact on JUNO

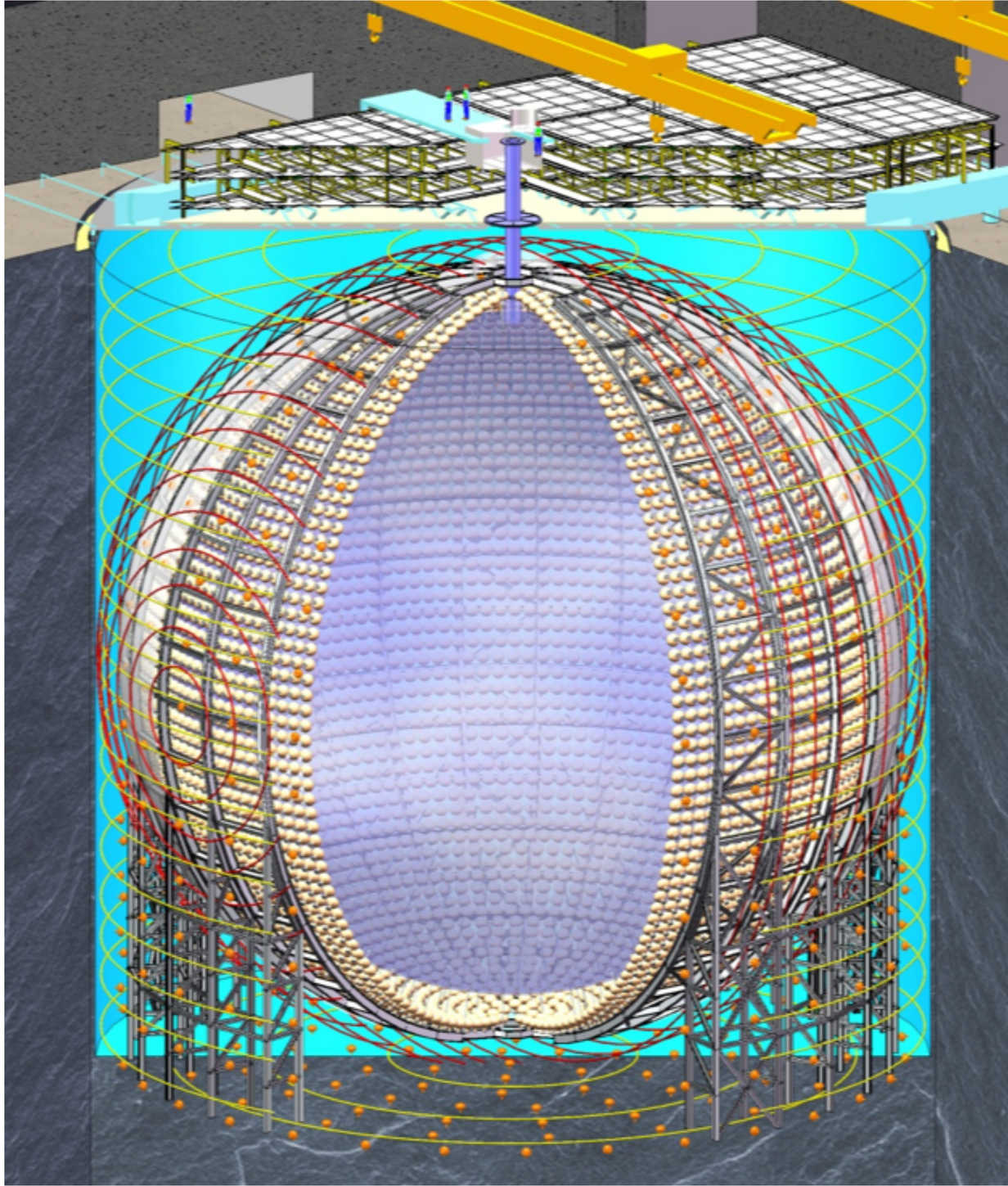
Given fine structure effects, in the worst case:

- With 3.2% energy resolution, JUNO can achieve 3.8σ hierarchy determination after six years
- If they achieve their goal of 3% energy resolution: 5.8σ after six years
- Unrelated effects may reduce this projected significance. But **fine nuclear structure effects are not the serious impediment they have been taken to be.**
- Near detector development should *not* center on nuclear fine structure, as has been claimed.



Outlook

- JUNO is a very challenging experiment
- Unprecedented energy resolution (~3%)
- Unprecedented control of energy response (<0.5%)
- But impact of fine structure has been overstated



Thank you.

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Reactor neutrino spectral distortions play little role in mass hierarchy experiments

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